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Study of Egyptian castor biodiesel-diesel fuel properties and diesel engine performance for a wide range of blending ratios and operating conditions for the sake of the optimal blending ratio

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ABSTRACT

Egyptian Castor raw oil has been used to produce Castor Methyl Ester (CME) biodiesel utilizing Transesterification-ultrasonic process. To meet the ASTM requirements, CME was blended with the conventional diesel fuel for improving sooting tendency and fuel viscosity. Thermal analysis showed that CME has comparable end-boiling temperature and fuel-air mixing of the diesel fuel. Experiments on a single-cylinder engine in accordance to G-2 of ISO 8718 standard were conducted at wide ranges of blending ratios and operating conditions. Comparing to the neat diesel fuel data, the results of testing CME biodiesel fuel showed that (i) a maximum increase of 8% in the brake specific energy consumptions was received at a blending ratio of 30%, (ii) a slight increase in the brake thermal efficiency (around 1%) was obtained at a blending ratio of 20%, (iii) the best reduction in the carbon monoxide emission (CO), unburned hydrocarbons (HC), nitrogen oxides (NOx) were 17%, 40%, and 0.05%, respectively as recorded at a blending ratio of 10%, (iv) the best reduction of 7.5% in carbon dioxide emissions was observed at 20% blending ratio, and (v) the minimum opacity level was observed at a blending ratio of 30%. The results conclude that the 20% blending ratio is recommended to keep high engine efficiency without environmental deterioration.

1. Introduction

Fuel consumption in the transportation sector increases annually with a rate of 1.4%. Diesel fuel has the highest consumption compared to the other fuels as shown in Fig. 1 [1]. The fossil fuel depletion problem is currently facing all the countries of the world. It is necessary to find alternatives non-fossil fuels for the transportation sector. In the recent decades, there was a great attention to use biofuels as an effective alternative of the diesel fuel [2]. The advantages of biodiesels to be used as alternative fuel are the null impact on the greenhouse phenomena, lower emissions due to existing of oxygen compound in fuel structure, biodegradable…etc. [3,4]. Biodiesel is usually prepared from fatty acids (FA) in vegetable oils and animal fats by reacting them with alcohols catalyzed using acid/base catalyst. The feedstock of vegetable oils may be edible oils (first generation) or non-edible oils (second generation). Recently, non-edible feedstock seems to be more attractive for biodiesel production to overcome on any crisis related to food production [5].

In Egyptian territory, there are many suitable non-edible feedstocks that possess high oil contents in their seeds; such as Jatropha, Jojoba, Palm seed, Castor, and others. The biodiesel production cost depends mainly on the cost of the raw oil (around 75% of cost is paid to get the raw oil) [6]. Using low-priced feedstock, the biodiesel production cost may be reduced and approached that of the petrol diesel fuel [7,8]. After reviewing the prices of the non-edible oils in Egypt, it was found that the price of Castor oil is the cheapest one, then Jatropha, while Jojoba has the highest price. Considering the high availability and the low cost of castor raw oil in Egypt, it is attractive to check its viability to produce biodiesel and to examine its effect on the diesel engines performance.

Castor plants (*Ricinus Communis* L.) can be cultivated in marginal lands with low water demands. Seeds of castor need four months for harvesting with relatively high oil contents (around 50% by weight). The chemical structure of the castor raw oil possesses three chemical groups; carboxyl, hydroxyl and carbon-carbon double bond. Castor oil is suitable for industrial applications rather than food applications

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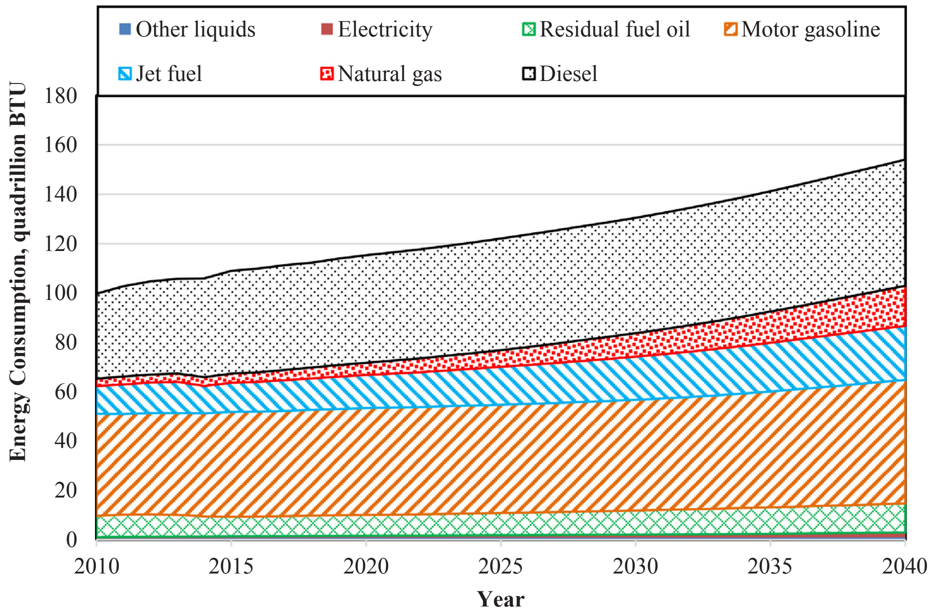
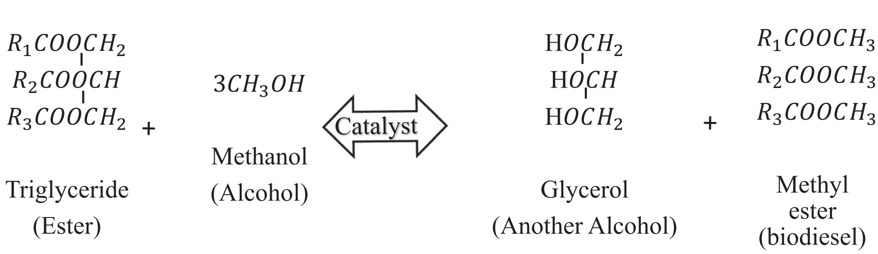


Fig. 1. World energy consumption by transportation sector [1].

[9,10]. Castor raw oil has additional unusual chemical composition feature related to the type of its fatty acids; triglyceride with 18-carbon hydroxylated FA and a single double bond [11]. Additional advantages and disadvantages feature of Castor oil are:

A. Advantages of castor oil to be used as a biodiesel feedstock: -
  - Nonvolatile oil, yellow-green/yellow-brown color, odorless, and has unpleasant taste.
  - High soluble in alcohol due to high FA.
  - Relatively high calorific value (more than 40 MJ/kg) and the high cetane number with low phosphorous content and carbon residues.
  - Withstand carbonization at high temperature (up to 350 °C); so it is used for race engine lubrication.
B. Disadvantageous of castor oil opposing its direct use in engines: -
  - High compressibility and viscosity; so it is hard to inject and extract castor oil.
  - High water content that may lead to problems related to corrosion and inefficient filtration.

The most effective, economic and easy way to produce biodiesel from raw oils is by realizing the transesterification process (catalyzed chemical reaction where oil and alcohol react in a reversible reaction to provide yield fatty acid alkyl esters as given in the following chemical equations [3,12]:



The completeness of the conversion process to ester depends mainly on the type of catalyst, catalyst portion, alcohol-to-oil molar ratio, reaction duration, mixing rate, and reaction temperature [13]. Among the different catalysts, alkaline metal hydroxides (as Potassium Hydroxide - KOH and Sodium Hydroxide - NaOH) are the most recommended catalysts with a weight ratio of 0.5 to 2.7% [14,15]. For oils possessing high contents of free fatty acids (FFA), the single step reaction (transesterification) shall be replaced by the two step reactions (esterification to neutralize unreacted acids then transesterification reaction) [7]. Alkaline catalysts are preferred for FFA < 3 %wt. In this case any oil containing acid value less than 2 mg KOH/g can be converted into biodiesel by a single step reaction (transesterification) [7]. Most of castor oils have acid value less than 2 mg KOH/g; so, the single step reaction is sufficient for biodiesel production. The most used alcohols are methanol and ethanol. The use of methanol has faster reaction [16,17].

The stochiometric alcohol-to-oil molar ratio includes one mole of triglyceride oil and three moles of alcohol to produce three moles of fatty acid alkyl ester plus one glycerol mole. The actual ratio would be many times the stochiometric value to provide high yield of ester from this reversed reaction. The reported alcohol-to-castor oil molar ratio varies from 9:1 to 20:1, while other parameters as the reaction time and temperature are varied from lower than 1 hr up to 10 hr, and from 30 °C up to 70 °C, respectively [15]. The corresponding yield of the produced Castor Methyl (or ethyl) Ester (biodiesel)-CME (or CEE) varies from around 40% up to 90% with optimal predicted values in the range 75–85% [15].

In the literature, simply stirrer (with speed from 600 up to 1200 rpm) was mostly used for the reactants mixing. The reactants mixing process can be optimized using ultrasonicator. This novel technology enhances the mass transfer between reactants leading to significant reductions in the reaction duration and the production cost [17,18]. The use of ultrasound for reactants mixing leads to higher yield of the CME (86.6%), lower methanol-to-castor oil molar ratio (8.87:1)